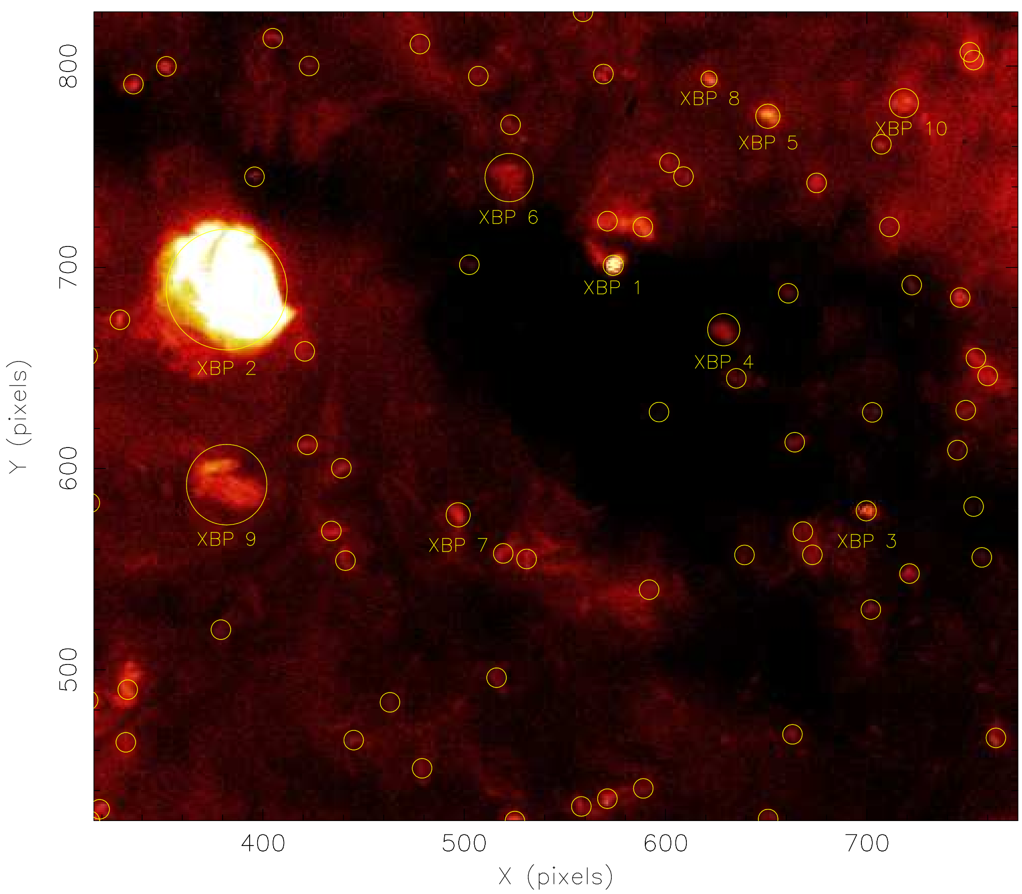

Figure 1. Here we see a 459 pixel by 402 pixel region of the X-ray emitting atmosphere of the Sun. Data are from Hinode's X-Ray Telescope (XRT) on January 11, 2011 at 18:14 UT. Pixels are 2 x 2 arcsec in size.

Hinode X-ray Bright Points: Solar Micro-flares in Action

Sunspots represent only one of many interesting phenomena on the Sun. In the corona, the highest and hottest layer[1] of the solar atmosphere, we see *X-ray Bright Points* (XBPs). XBPs are small (5 - 60 arcsec), compact bright spots, observed in X-rays. With Hinode's XRT we have seen that XBPs are made up of tiny magnetic loops. Most XBPs are created when pairs of wandering opposite-magnetic-polarity (north/south) strands of photospheric magnetic field collide and cancel. The cancellation releases stored magnetic energy that heats up the corona to produce XBPs. Because this is similar to how solar flares work, we can think of XBPs as tiny flares, or micro-flares.

In Figure 1 XBPs are circled in yellow and ten are numbered. The full image is 459 pixels x 402 pixels. Each pixel is 2 arcsecond x 2 arcsecond on a side. For comparison, Earth, with a diameter of 12,756 km at the equator, would be only about 8 pixels across (assuming 1547 km/pixel).

Problem 1: If the diameter of the Sun is 1800 arcseconds and the radius is 696,000 km, what is the scale of the image in **A)** kilometers per arcsecond (km/arcsecond)? **B)** kilometers per millimeter (km/mm)?
Problem 2: With a ruler, measure the diameter of each of the numbered XBPs in the image (in mm), record it in the table, and calculate the radius of each XBP in kilometers (diameter/2 times scale value in km/mm from problem 1). All XBP labels are below their associated bright point.
Problem 3: If the image above represents a typical region, how many XBPs cover the solar surface? There are 71 bright points in the image (identified with a computer program). Hint: The Sun is a sphere.
Problem 4: Fill in the following table and make a graph of brightness vs. radius. To do this, first, normalize radius and summed brightness with the largest value so that all the data are between 0 and 1. For example, you would divide all the numbers in the Summed Brightness column by 6.5×10^5. Next, plot the data on log/log paper.

XBP Number	Measured Diameter millimeters (mm)	Calculated radius kilometers (km)	Normalized Radius	Summed Brightness (Counts)	Normalized Brightness
1				7.2×10^3	
2				6.5×10^5	
3				2.1×10^2	
4				2.6×10^3	
5				3.8×10^3	
6				5.0×10^3	
7				1.9×10^3	
8				1.4×10^3	
9				1.4×10^5	
10				2.3×10^3	

Answer Key:

Problem 1: If the diameter of the Sun is 1800 arcseconds and the radius is 696,000 km, what is the scale of the image in **A)** kilometers per arcsecond (km/arcsecond)? **B)** kilometers per millimeter (km/mm)?

Answer:

A) The solar radius is

$$1800\ arcseconds \div 2 = 900\ arcseconds, \tag{1}$$

which physically equals 696,000 km, so the scale is

$$696,000\ km \div 900\ arcseconds = 773\ km/arcsecond. \tag{2}$$

B) The image is 459 pixels across in the "x-direction", which measures 122 millimeters (mm) with a ruler. In the "y-direction", the image is 402 pixels high, which measures 107 mm. Each pixel is 2 arcseconds in size, so in the "x-direction",

$$773\ km/arcsec \times 459\ pixels \times 2\ arcssec/pixel = 710,000\ km. \tag{3}$$

In the "y-direction",

$$773\ km/arcsec \times 402\ pixels \times 2\ arcssec/pixel = 621,000\ km. \tag{4}$$

From the left edge of the image to the right edge, the ruler measures a distance of about 112 mm (note: results may vary slightly due to different printers), so the image scale in the "x-direction" is

$$710,000\ km \div 122\ mm = 5819\ km/mm. \tag{5}$$

The scale in the "y-direction" is

$$621,000\ km \div 107\ mm = 5803\ km/mm. \tag{6}$$

Problem 2: With a ruler, measure the diameter of each of the numbered XBPs in the image (in mm), record it in the table, and calculate the radius of each XBP in kilometers (diameter/2 * scale value in km/mm from problem 1). All XBP labels are below their associated bright point.

Answer:

For each numbered XBP, measure the diameter of the circle that marks it. Assume that the scale is the same in the x- and y-directions and do the calculation only for the x-direction. For example, for XBP 2, the diameter is 1.8 mm. The radius is one-half the diameter, equal to 0.9 mm. The radius in kilometers is then calculated in the following way:

$$0.9\ mm \times 5819\ km/mm = 5237\ km \tag{7}$$

where 5819 km/mm is the scale factor you calculated in problem 1. Your results may be slightly different because of using a different printer.

Problem 3: If the image above represents a typical region, how many XBPs cover the solar surface? There are 71 bright points in the image (identified with a computer program). Hint: The Sun is a sphere.

Answer:

The sun is a sphere with a radius of 696,000 kilometers. The area of a sphere is given by $4\pi R^2$, so the surface area of the sun is

$$4 \times 3.14 \times (696,000\ km)^2 = 6.08x10^{12} km^2. \tag{8}$$

The size of the Hinode image is 709,614 km on the horizontal side and 621,492 km on the vertical side.

$$710,000\ km \times 621,000\ km = 4.41x10^{11} km^2. \tag{9}$$

Note, this is an approximation because of the distortion of a flat image attempting to represent a curved spherical surface. The actual solar surface area covered is actually a bit larger.
The surface area of the Sun is about

$$6.08x10^{12} km^2 \div 4.41 \times 10^{11} km^2 = 14 \tag{10}$$

times larger than the Hinode image.
Since there are 71 XBPs in the Hinode image, there would be

$$71 \times 14 = 994 \tag{11}$$

bright points covering the full solar surface if the Hinode image is typical.

Problem 4: Fill in the following table and make a graph of summed brightness vs. radius. To do this, first, normalize your numbers with the largest value so that all the data are between 0 and 1. For example, you would divide all the numbers in the calculated radius column of the table by 48,863 and divide all the numbers in the Summed Brightness column by 6.5×10^5. Next, plot the data on log/linear paper.

Answer: Your measured results may vary, hence the calculated results will also be different. Errors of up to ±3 mm would be acceptable. The graph shows no clear relationship between XBP brightness and size, although there is a cluster of points near the center of the graph that appear to be related. This lack of a definitive answer (a null result) is okay in science. However, the scientist must then try to understand why there is a null result. In this particular case, the brightness of each XBP is determined by the evolution of the individual point. If a mini-flare has just happened, the XBP will be very bright. If in the time history, our observation takes place a long time from the flare event, the XBP will be dim. So the lack of a relationship between size and brightness is not very surprising.

XBP Number	Measured Diameter millimeters (mm)	Calculated radius kilometers (km)	Normalized Radius[2]	Summed Brightness (Counts)	Normalized Brightness
1	3.0	8,729	0.18	7.2×10^3	0.011
2	16.8	48,880	1.00	6.5×10^5	1.000
3	3.0	8,729	0.18	2.1×10^2	0.003
4	4.2	12,220	0.25	2.6×10^3	0.004
5	3.3	9,601	0.20	3.8×10^3	0.005
6	6.2	18,039	0.37	5.0×10^3	0.008
7	3.1	9,019	0.18	1.9×10^3	0.003
8	2.1	6,110	0.12	1.4×10^3	0.002
9	10.6	30,841	0.63	1.4×10^5	0.033
10	3.9	11,347	0.22	2.3×10^3	0.004

[1]Extra Reading:

For a discussion of the layers of the Sun, begin with: http://solarscience.msfc.nasa.gov/interior.shtml. Links on the left of the page will take the reader to different layers of the Sun.

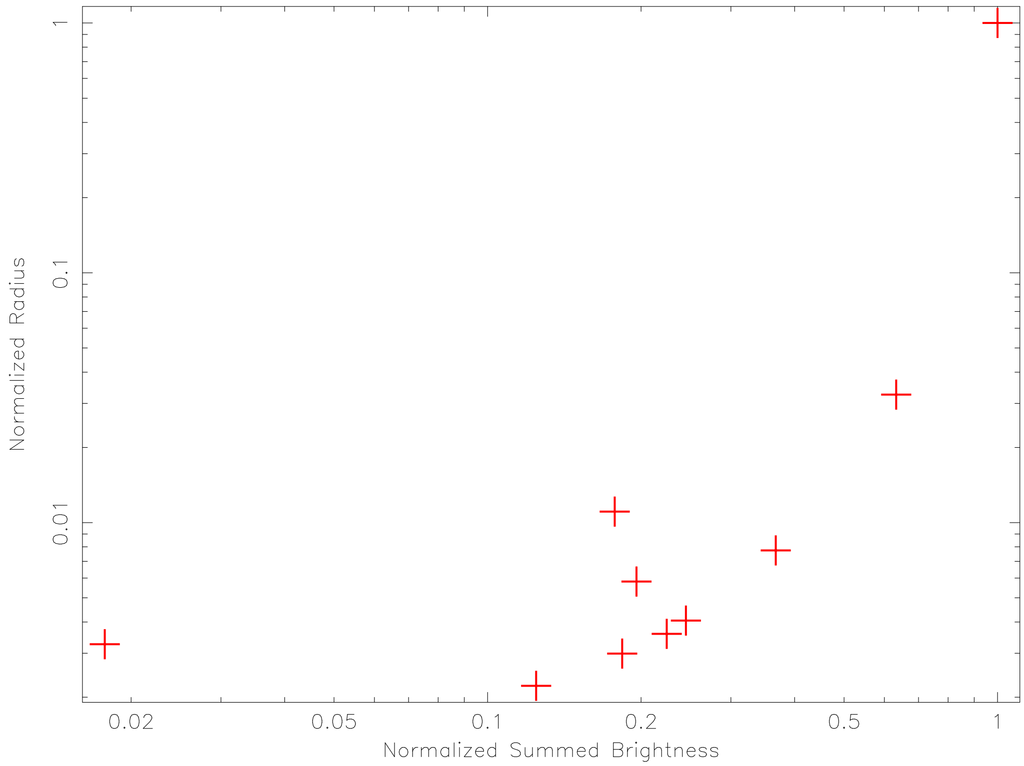

Figure 2. The graph is of the normalized radius of each numbered bright point versus the normalized-summed brightness. Note, since these quantities are normalized, they have no units (i.e. kilometers divided by kilometers equals 1).

[2]Scientific Notation and Significant Figures:

The normalized values in the table are not representative of the rules for significant figures, but are shortened for clarity and space. To express the first value of normalized radius properly (and to easily see how it's done), convert the numbers to scientific notation: $8,729 \rightarrow 8.729 \times 10^3$ has four significant figures and $48,880 \rightarrow 4.888 \times 10^4$ also has four significant figures. Now to normalize, one must divide 8,729 by 48,880. Since the answer cannot have more significant digits than any one of the input measurements used (in this case, they are the same), the answer should be 1.786×10^{-1} or 0.1786.

This activity has been modified by Mitzi Adams from one created by Dr. Sten Odenwald for the Hinode Project's Education and Outreach program. More mathematics and physics activities may be found at *Spacemath*, http://spacemath.gsfc.nasa.gov.